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Waterways Experiment Station

A Comparison of Methods to Reduce Potential Peak Flow on the West Fork Cedar River Watershed, Iowa

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Prepared for Scientific Assessment and Strategy Team (SAST)

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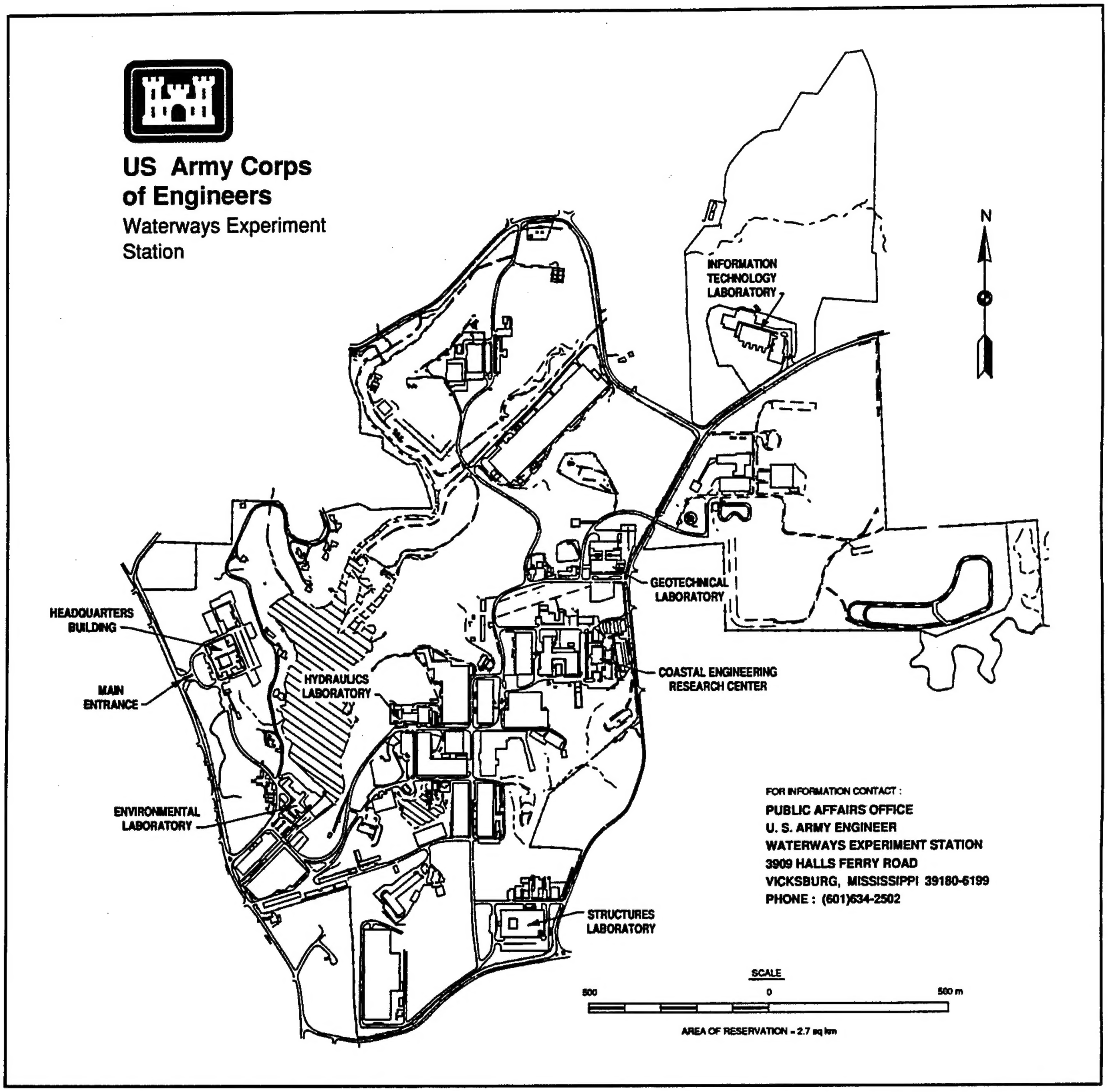

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Preface

This study was conducted by the Hydraulics Laboratory (HL) of the U.S. Army Engineer Waterways Experiment Station (WES) during the period of January to March 1994 and was sponsored by the Scientific Assessment and Strategy Team. The study was conducted and the report prepared by Mr. Jeffrey D. Jorgeson, Watershed Systems Group, Hydro-Science Division (HSD); and Mr. Billy E. Johnson and Dr. Gary E. Freeman, Rivers and Streams Branch (RSB), Waterways and Estuaries Division (WED), HL.

This report was prepared under the direct supervision of Mr. William D. Martin, Chief, HSD; Mr. Michael J. Trawle, Chief, RSB, WED; and under the general supervision of Mr. William H. McAnally, Chief, WED; Mr. Robert F. Athow, Acting Assistant Director, HL; and Mr. Richard A. Sager, Acting Director, HL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin and Commander was COL Bruce K. Howard, EN.

1 Introduction

By direction from the White House, the Scientific Assessment and Strategy Team (SAST) was created in November 1993 to provide technical and scientific guidance related to recovery efforts from flooding in the Upper Mississippi River Basin that occurred in the spring and summer of 1993. During that flood, peak discharges exceeded all previous peak discharges on record for many locations, and the costs were high in both human and economic terms. In spite of those negative impacts, the flooding had some beneficial impacts as well, such as improved spawning areas and reconnection of the main channel with backwater areas in some locations. This combination of negative and positive impacts raised many longstanding issues related to flood control and habitat restoration. Thus, the SAST was formed to provide scientific advice to decision makers on recovery efforts and on future floodplain management issues (SAST 1994).

The overall SAST effort was multifaceted and included the generation of a multilayer, multiresolution database encompassing the Upper Mississippi River Basin. A variety of other products from the database were also produced, including maps, illustrations, analysis results, and statistical information. Ultimately, the results of the SAST were documented in a multi-volume report (SAST 1994).

One of the specific efforts undertaken by the SAST was to evaluate the potential impacts of various nonstructural approaches to watershed management on flood control through peak flow reduction. These watershed management approaches included reducing the amount of excess precipitation available for runoff by maximizing surface infiltration, restoring wetlands to reduce peak flows by temporarily storing runoff and attenuating the flood peak, and creating small detention basins to temporarily store runoff and reduce the peak flow. The SAST determined that upland watersheds were the best locations for applying these methods because upland watersheds generally cover larger land areas than the floodplains adjacent to main channels. To analyze these nonstructural approaches, four watersheds were selected for modeling, with each watershed being representative of a different terrain.

At the request of the SAST, the Hydraulics Laboratory at the U.S. Army Engineer Waterways Experiment Station (WES) conducted a model study on one of those four watersheds, the West Fork Cedar River in Iowa. The

purpose of the study was to evaluate the potential effects of several proposed nonstructural watershed management alternatives on reducing the peak flow from the watershed at its outlet near Finchford, IA. The hydrologic analysis software GeoShed was used to set up an HEC-1 model of the watershed, the HEC-1 model was verified to several observed events, and the proposed alternatives were then run with the model and the resultant peak flows determined. The methodology used in modeling the watershed, the proposed alternatives that were evaluated, and the results of the study are presented herein.

2 Background

Watershed Geography

The West Fork Cedar River is located in northern Iowa, and its watershed encompasses approximately 2,200 sq km above the gaging station at Finchford, IA. The watershed is fan-shaped and is about 100 km long and 50 km wide at the widest point. The headwaters of the river form in Beaverdam Creek and the East Branch of Beaverdam Creek just below Clear Lake and Mason City, IA. The West Fork Cedar River is formed when those two creeks join about 15 km farther south between Sheffield and Rockwell, IA. From that point, the river flows generally southeast to the gaging station at Finchford, IA, nearly 80 km away. Tributaries to the river include Bailey Creek, Hartgrave Creek, and Maynes Creek, all of which join the West Fork Cedar River from the west. The West Fork Cedar River joins the Shell Rock River a few kilometers below Finchford, IA, and just downstream they flow into the Cedar River just above Cedar Falls, IA.

Watershed Topography

The upper reaches of the watershed, where Beaverdam and the East Branch of Beaverdam Creeks form, are characterized by hummocky topography and poorly defined drainage. From this area, the West Fork Cedar River flows into an area of more gently rolling hills and well-established drainage. The remaining course of the river has a wide alluvial plain, low stream gradient, and valleys that blend in long gentle slopes with the uplands. Relative to mean sea level, the elevation in the headwater area is approximately 380 m and the outlet of the watershed at Finchford, IA, has an elevation of 267 m (U.S. Department of Agriculture 1974).

3 Watershed Model

Modeling of the West Fork Cedar River was divided into two separate tasks; a digital watershed model and an HEC-1 runoff model. The digital watershed model was created using digital elevation and stream location data as detailed in the remainder of this chapter and served as a basis for estimating many of the input parameters required for the HEC-1 model. Creation of the HEC-1 model is discussed in the following chapter.

GeoShed

The watershed for the West Fork Cedar River was modeled with GeoShed, a surface water hydrology modeling package jointly developed by the Engineering Computer Graphics Laboratory of Brigham Young University and the WES. GeoShed uses digital elevation data to generate a triangulated irregular network (TIN), from which watershed and subbasin boundaries are automatically delineated. GeoShed also allows stream networks to be manually defined, automatically generated, or imported digitally. After subdividing the watershed into appropriate subbasins, GeoShed calculates various hydrologic parameters for each subbasin. The hydrologic parameters that can be calculated for each subbasin include basin area, average basin slope, average overland flow distance, maximum flow distance, slope of the maximum flow distance, distance from the centroid of the basin to the stream, stream segment lengths, stream slopes, and several others. An interface is also provided to create HEC-1 input files and for viewing hydrographs generated with HEC-1 (Brigham Young University 1992).

To construct a TIN, data points with x,y,z[1] coordinates are required. The x,y,z values, typically in a rectangular coordinate system, represent the easting (x), northing (y), and elevation (z) of a point. The points are connected to form a network of triangles where the points serve as the vertices of the triangles. Figure 1 depicts a sample TIN constructed from a set of scattered data points.

[1] For convenience, mathematical symbols and abbreviations are listed in the notation (Appendix A).

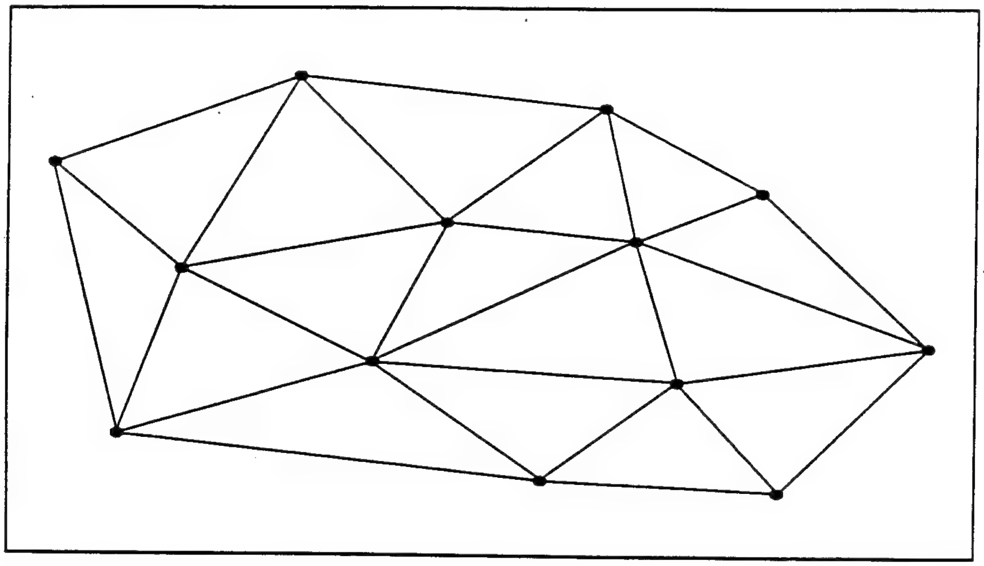

Figure 1. Sample TIN

Once a TIN has been generated, it can serve as an excellent tool in the process of watershed analysis. Methods have been developed which use the geometric information contained in the TIN to define the areas which contribute flow to a given point, and these methods can be used to easily delineate watershed boundaries. After the watershed is delineated, the TIN serves as an excellent basis for computing geometric properties of the watershed such as area, average slope, and flow distances.

Elevation Data

The basic input required for GeoShed is digital elevation data for the area to be modeled. The digital elevation data must have X and Y coordinates and an elevation for each point. The digital elevation data used to model the West Fork Cedar River came from United States Geological Survey (USGS) 1-Degree Digital Elevation Models (DEM). The basic elevation models for the 1-Degree DEMs are produced by the Defense Mapping Agency using cartographic and photographic sources, but are distributed by the USGS using a different record format. Each 1-Degree DEM covers a 1-deg by 1-deg block and contains a 1201 X 1201 grid, or 1,442,401 elevation points. Spacing of the elevation points in the grid is 3 arc-seconds, which is approximately 60 m east-west and 90 m north-south in the vicinity of the West Fork Cedar River watershed. Elevations in the DEMs are provided in meters relative to mean sea level (U.S. Department of the Interior 1987).

Elevation Data Processing

To encompass the entire watershed of the West Fork Cedar River, portions

of four separate DEMs were joined. Those DEMs were Waterloo West, Waterloo East, Mason City West, and Mason City East. The resultant DEM contained an 841 X 1441 grid, or 1,211,881 elevation points. GeoShed is theoretically capable of working with that many data points, but the computational time and graphical displays using that many points are undesirable. Therefore, the digital elevation data were resampled to a coarser grid to reduce the total number of points. The resampling was performed by averaging the nine elevations contained within each 3 X 3 grid and placing that average elevation at the center of the 3 X 3 grid. Thus, the digital elevation data were reduced to a 280 X 480 grid, or 134,400 elevation points. The elevation grid was then filtered using linear and non-linear filters such that elevation points which represented peaks, pits, valleys, ridges, and breaks in slope were retained while elevation points in areas with little or no change in slope were filtered out of the grid (Southard 1990). The result of this filtering was a data set containing only those points necessary to depict important topographic features. These filtered elevation data were then put into the proper format and read into GeoShed. Triangulating the points in GeoShed produced a TIN representing the topography of an approximately 6,500-sq-km rectangular area which encompassed the West Fork Cedar River watershed.

Stream Network

In addition to elevation data, a stream network was required in GeoShed to complete the watershed model. For the West Fork Cedar River, the stream network was digitized from 1:100,000 scale USGS planimetric maps, and the digitized stream network was imported into the West Fork Cedar River TIN in GeoShed. Based upon this stream network, locations of the outlets for several subbasins were identified and, based upon those locations, the subbasins were delineated as described later in this chapter.

Watershed and Subbasin Delineation

The next step in creating the digital watershed model was to delineate the boundary of the West Fork Cedar River from the rectangular TIN discussed previously. The gage at Finchford, IA, was selected as the outlet for the watershed, and GeoShed was used to automatically delineate the watershed area.

Jones, Wright, and Maidment (1990) proposed an algorithm for automated watershed delineation using TINs. While that technique worked well in most cases, there were several shortcomings. Nelson, Jones, and Miller (1994) addressed those shortcomings and set forth a new algorithm that precisely delineates watershed boundaries using a TIN model. This algorithm is used to define the boundary of an area contributing to the flow at a single point or for multiple watersheds in a stream network. This algorithm, as set forth by

Nelson, Jones, and Miller (1994), is the one used in this project and is detailed below.

The most fundamental aspect of the watershed delineation method is tracing flow paths on the TIN. Assuming that roughness and momentum are negligible, the direction of flow of water across a surface will be in the direction of steepest descent, i.e., the direction of the maximum downhill gradient. Jones, Wright, and Maidment (1990) described this process and showed that flow paths can be constructed from any arbitrary point on a TIN by following the path of maximum downward gradient from triangle to triangle. The path of flow is orthogonal to the contour lines on any given triangle.

This is illustrated in Figure 2, which shows several triangles with contour lines, and a sample flow path along the path of maximum downward gradient. Notice that in Figure 2 all of the flow occurs across the faces of the triangles. If the flowpath were to have intersected an edge between two adjacent triangles which both slope towards each other, then the flow would have continued downward along that edge. By following this succession of flow, either down across the triangle faces or down along triangle edges and always along the path of steepest downward gradient, the flowpath can be traced to a terminus. That terminus can be either a pit or local depression in the interior of the TIN, a boundary on the exterior of the TIN, or a user-defined point at any location in the TIN.

The drainage basin or watershed area for any given terminus point is determined by defining the set of triangles that contribute flow to that terminus. This set of triangles is determined by generating a flowpath at the centroid of each triangle in the TIN and following each flowpath in the direction of maximum downward gradient until it intersects a terminus. All such triangles whose flowpaths intersect a given terminus are then said to contribute flow to that terminus. This is then the set of triangles which comprise the drainage basin for that terminus, and the perimeter of that set of triangles is defined as the watershed boundary. In most cases, there are triangles whose flow intersects the TIN boundary before it reaches a terminus point. Those triangles are not considered to contribute to any basin, and may either be ignored or discarded from the TIN.

This process was performed for the West Fork Cedar River Watershed. The terminus point was selected as the outlet of the watershed near the gage at Finchford, IA. The triangles which contributed flow to that point were identified, and the remaining portions of the TIN which were outside of the watershed were deleted from the TIN. The result was a TIN which served as a digital model of the West Fork Cedar River watershed. To model the watershed using HEC-1, it was desirable to subdivide the area into a series of smaller subbasins. This was also accomplished using GeoShed. There is no significant variation in land use or soil types over the watershed, so the criteria used to subdivide the watershed were topography and generally uniform subbasin size. The outlet of each desired subbasin was identified, the boundaries of the resultant subbasins were delineated by GeoShed, and the entire

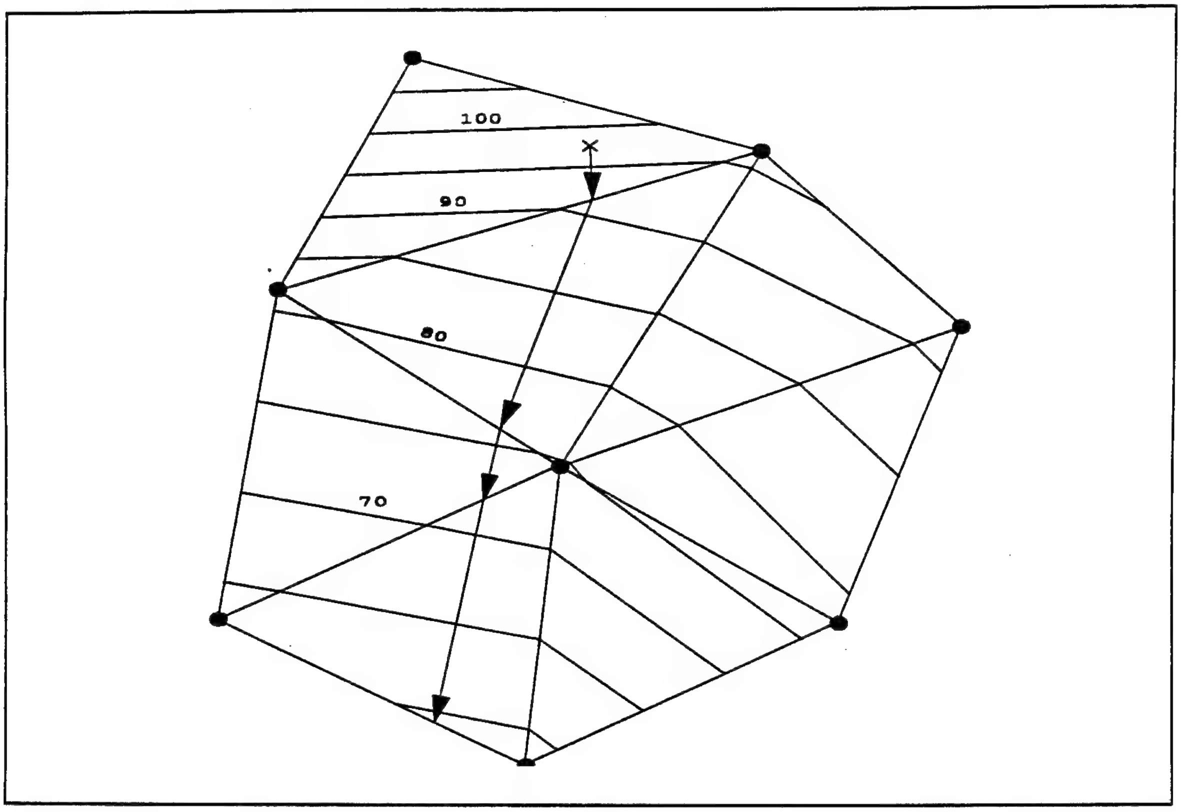

Figure 2. Path of maximum downward gradient

watershed was divided into 11 subbasins ranging in size from approximately 150 sq km to 270 sq km. Figure 3 shows the West Fork Cedar River watershed and its stream network, and Figure 4 shows the West Fork Cedar River watershed and subbasins.

Basin Geometric Parameters

After defining a watershed area as described above, the underlying TIN serves as an excellent base from which to automatically compute the geometric parameters for that watershed required in a hydrologic model (Nelson, Jones, and Miller 1994). The TIN is comprised entirely of a set of triangles, and each of the triangles in the TIN is defined by three vertices with known coordinates. Thus, the information required to compute geometric properties such as area, slope, flow distances, and centroid is contained in the TIN, and the computation of those geometric properties is a fairly straightforward procedure. In this project, three specific geometric properties were considered for each watershed. Those properties were the area, the average slope, and the maximum flow distance within each subbasin. The area for each subbasin was determined by simply summing the areas of all triangles which belong to that subbasin. The average slope for each subbasin was determined by computing a weighted average of the slopes based upon the relative area of each triangle

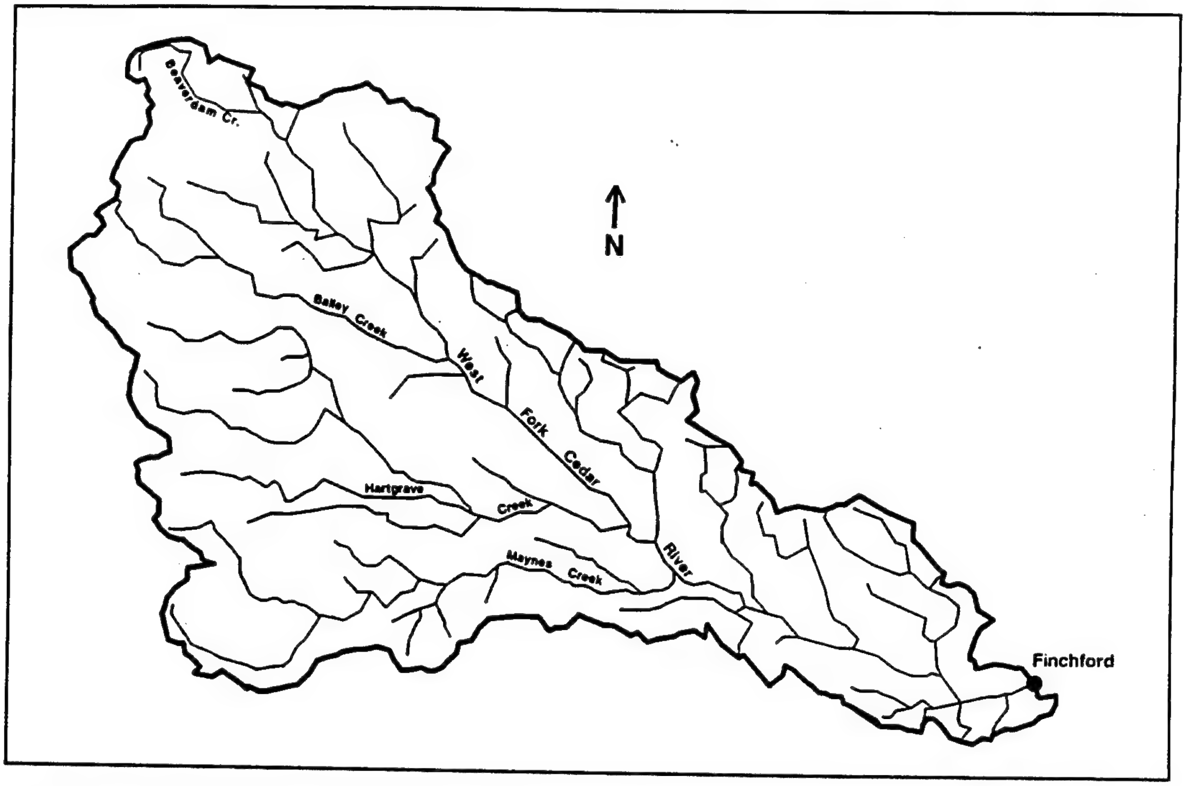

Figure 3. West Fork Cedar River watershed and stream network

in the subbasin. Earlier in this chapter, the method of determining the flowpath on a TIN from a given point was outlined. That method involved following the path of maximum downward gradient from a given point to a terminus. The maximum flow distance in each subbasin was determined by comparing the lengths of all flowpaths initiated from the centroid of each triangle in the basin to the terminus. The longest of those was taken as the maximum flow distance for the subbasin. Details of how these geometric parameters were used in the HEC-1 model are contained in the following chapter, and Table 1 provides a summary of the geometric parameters computed for each of the subbasins of the West Fork Cedar River that were used in this study.

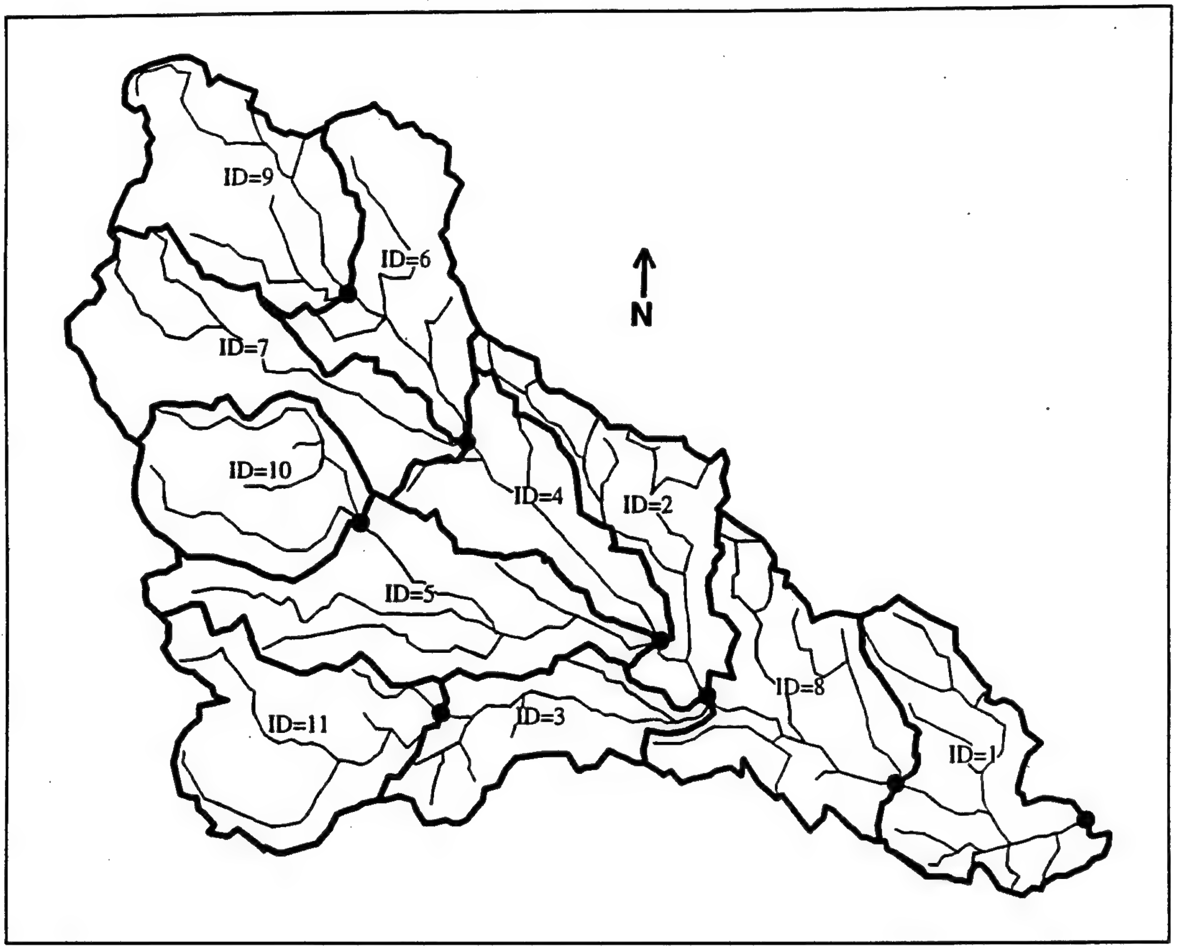

Figure 4. West Fork Cedar River watershed and subbasins

Table 1
Summary of Subbasin Geometric Parameters

Subbasin	Area, km^2	Average Slope, m/m	Maximum Flow Distance, m
1	200.5	0.0144	31,084
2	173.3	0.0086	34,965
3	147.8	0.0110	30,181
4	152.5	0.0112	27,845
5	269.8	0.0091	45,241
6	186.7	0.0076	32,877
7	235.3	0.0083	37,979
8	232.5	0.0146	27,169
9	219.1	0.0070	30,158
10	181.5	0.0075	24,177
11	222.3	0.0094	33,599

4 HEC-1 Model

HEC-1

The hydrologic model used for this project was the HEC-1 model developed by the U.S. Army Corps of Engineers, Hydrologic Engineering Center. HEC-1 simulates the surface runoff response of a watershed to a given precipitation event. The watershed is typically subdivided into subbasins, each representing a surface runoff entity connected by stream channels. Thus, the runoff from each subbasin is computed, combined with runoff from other subbasins, and routed through the channels to derive a hydrograph at the desired location, which for this project was the gaging station at Finchford, IA. A basic assumption in HEC-1 is that the hydrologic processes in each subbasin can be represented by parameters which reflect average conditions within the subbasin. HEC-1 simulations are limited to single storm events, as there is no provision for soil moisture recovery between storms (U.S. Army Corps of Engineers 1990).

HEC-1 Input File

The HEC-1 manual provides detailed information on the structure and requirements of HEC-1 input files for various applications of the model. The specific requirements of HEC-1 are not detailed in this report, but the options used in modeling the West Fork Cedar River will be discussed. The following sections detail the major components of the HEC-1 input file created for this watershed.

Loss method

In any hydrologic model, some means of estimating the amount of rainfall that becomes runoff must be used. During a rainfall event, some portion of the rainfall is lost to infiltration, evapotranspiration, interception, and other minor losses. Some portion of the losses are termed "initial abstractions" in that they must be satisfied prior to any runoff occurring. Additional losses continue to occur after runoff has commenced. To model this effect, loss rate

parameters must be established to account for the losses. After these losses have been estimated, the remaining rainfall, referred to as excess rainfall, becomes runoff.

The loss rate method chosen for this study was the curve number method developed by the U.S. Soil Conservation Service (SCS). The SCS curve number method was developed by studying the rainfall-runoff relationships from many small experimental watersheds. This method requires the assignment of a single parameter referred to as the curve number or *CN*. The *CN* is a dimensionless parameter with valid values between 0 and 100. Higher values of the *CN* represent fewer losses and a higher amount of runoff, while lower values of *CN* represent higher loss rates and thus a smaller amount of excess rainfall which can become runoff. For example, a totally impervious area would be given a *CN* of 100, while natural surfaces such as pastures, meadows, woodlands, or cultivated land would have a *CN* less than 100 since some amount of losses will occur in these areas.

Derivation of the *CN* is based on the principle that the depth of excess precipitation or runoff P_e will be less than or equal to the depth of precipitation P. This excess precipitation P_e is the amount remaining after initial abstractions I_a and continuing abstractions F_a. Continuing abstractions are those that continue after runoff begins, and represent the additional depth of water retained in the watershed. F_a will be less than or equal to the potential maximum retention S. Figure 5 illustrates these relationships.

The potential runoff from a particular basin is defined as the total amount of precipitation remaining after the initial abstractions are satisfied, or P-I_a. The basic hypothesis of the SCS method is that the ratios between the two actual and potential quantities described here are equal, i.e.,

$$\frac{F_a}{S} = \frac{P_e}{P - I_a} \tag{1}$$

From the continuity principle for the values depicted in Figure 3, it can be seen that

$$P = P_e + I_a + F_a \tag{2}$$

Combining these two equations and solving for P_e gives

$$P_e = \frac{(P - I_a)^2}{P - I_a + S} \tag{3}$$

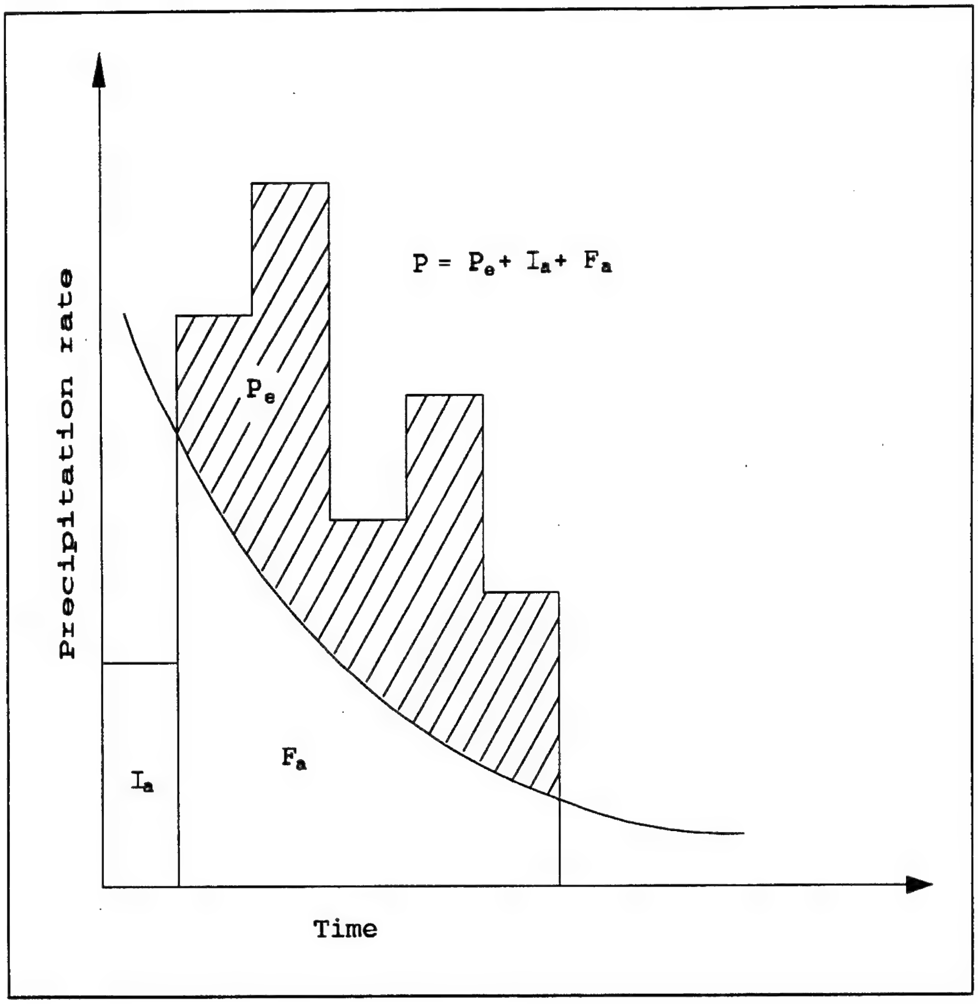

Figure 5. Excess precipitation and losses

This equation is used for computing the depth of excess rainfall, or direct runoff, from a storm by the SCS method. By study of results from a variety of watersheds, the following empirical relationship between I_a and S was developed:

$$I_a = 0.2\ S \tag{4}$$

Using this relationship in Equation 3 yields

$$P_e = \frac{(P - 0.2\ S)^2}{P + 0.8\ S} \tag{5}$$

Plotting data for P and P_e from many watersheds, the SCS established a family

of curves. These curves were standardized by using the dimensionless curve number CN which is related to S by

$$S = \frac{1000}{CN} - 10 \tag{6}$$

with S in inches. Thus, for a cumulative rainfall P and runoff curve number CN the cumulative direct runoff P_e can be determined (Chow, Maidment, and Mays 1988).

The SCS curve number method of computing losses was chosen for this project because several of the alternatives modeled in this study involve an estimated reduction in the SCS curve number based on various watershed management practices. Determination of the appropriate CN depends on the land use and soil type for the watershed. For the existing conditions on the West Fork Cedar River watershed, the Geographic Resource Analysis Support System (GRASS) Geographic Information System (GIS) was used to analyze the land use and soil data. Two grid coverages were established for the watershed area. One grid contained land use data while the other included soil type information. Based upon the land use and soil type, guidance from the SCS Technical Release 55 (TR-55) was used to determine a CN for each grid cell, and an average CN over each subbasin was computed for normal antecedent moisture conditions (U.S. Department of Agriculture 1986).

Unit hydrograph method

The unit hydrograph was first proposed by Sherman in 1932 and was originally called simply the unit-graph. The unit hydrograph for a watershed is defined as a direct runoff hydrograph resulting from one unit of excess rainfall generated uniformly over the drainage area at a constant rate for an effective duration (Chow, Maidment, and Mays 1988). There are several methods for generating a synthetic unit hydrograph for a basin or watershed, many of which employ some of the geometric parameters of the watershed in determining the unit hydrograph parameters.

The unit hydrograph chosen for modeling the West Fork Cedar River was the SCS dimensionless unit hydrograph. The SCS dimensionless unit hydrograph was derived from a large number of natural unit hydrographs from watersheds varying widely in size and geographical locations (U.S. Department of Agriculture 1985). This dimensionless hydrograph has its ordinate values expressed in the dimensionless ratio q/q_p, where q is the discharge at time t and q_p is the peak discharge. The abscissa values are expressed by the dimensionless quantity t/T_p, where t is the time and T_p is the time from the beginning of the rise to the peak. Figure 6 provides a plot of the SCS dimensionless unit hydrograph.

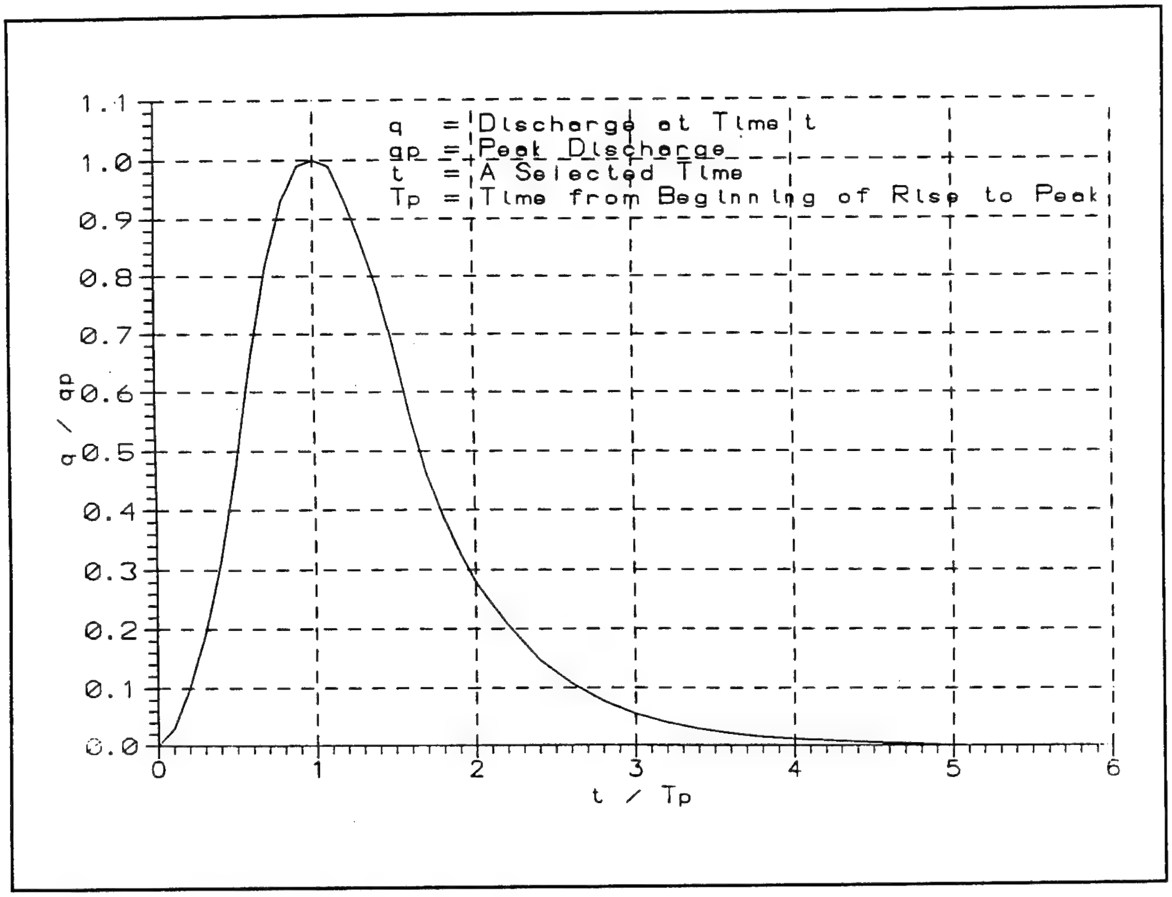

Figure 6. SCS dimensionless unit hydrograph

In the HEC-1 model, the SCS unit hydrograph is defined by a single parameter called TLAG, which is defined as the lag in hours between the center of mass of rainfall excess and the peak of the unit hydrograph. In HEC-1, the SCS dimensionless unit hydrograph parameters T_p and q_p are computed as follows:

$$T_p = 0.5 * \Delta t + TLAG \tag{7}$$

$$q_p = 484 * AREA \ / \ T_p \tag{8}$$

In the above equations, Δt is taken as the HEC-1 computational time interval and AREA is the area of the watershed or subbasin over which the unit hydrograph is to be applied. The value for AREA in this project was taken as the area determined from the TIN as described in Chapter 3. The only remaining value needed is that of TLAG, and the unit hydrograph can be determined from the q/q_p and t/T_p ratios shown in Figure 6.

The computation of TLAG can be done in several manners. The SCS (U.S. Department of Agriculture 1985) presents an equation which is based upon some of the watershed geometric parameters which can be computed from a TIN. That equation is as follows:

$$TLAG = \frac{L^{0.8} * (S + 1)^{0.7}}{1900 * Y^{0.5}} \tag{9}$$

where

L = maximum flow distance in the watershed (ft)
S = (1000/CN) - 10
Y = average watershed slope (%)

This provides a single equation which incorporates two of the watershed geometric parameters that can be calculated from a TIN model, i.e., the maximum flow distance and the average watershed slope. This is the approach used in this project to compute TLAG for input into HEC-1. The values for maximum flow distance and average watershed slope computed from the watershed model for the West Fork Cedar River for each subbasin, as presented in Table 1, were used to determine a TLAG value for each subbasin.

Routing method

To determine the runoff hydrograph at the outlet of the West Fork Cedar River watershed based upon the flow from each of the subbasins, the flow from each subbasin had to be routed through the channels leading to the outlet. There are various methods available within the HEC-1 model for performing the channel routing, and the Muskingum-Cunge routing method was selected for this model. For each routing reach, the Muskingum-Cunge method requires data on channel cross section, Manning's n value, channel slope, and channel length.

For this project, eight-point cross sections were entered for each routing reach, with a Manning's n value of 0.07 used for the overbank areas and 0.035 used for the channel. No detailed cross-section data were available for the watershed, but a field reconnaissance trip was made and general cross-section characteristics were obtained for most of the routing reaches. The length and slope of each routing reach were determined from the watershed TIN model.

HEC-1 Model Verification

The HEC-1 model of the West Fork Cedar River watershed was verified to two observed events using precipitation data from the three rain gages located in and near the watershed and streamflow data from the gaging station at

Finchford. Since the focus of this study was on the reduction of peak flows during times of significant flooding, two events with relatively large peak flows for this watershed were selected for verification of the model. The first verification event occurred during July 1990 with a peak discharge of 560 m^3/sec, and the second event occurred during March and April 1993 with a peak discharge of 500 m^3/sec. Those observed events were the second and third largest events, respectively, during the period of record for the Finchford gage, which covers the 48-year period from 1946 to 1993. The soil moisture conditions during each of these events were wetter than normal due to rainfall that had occurred within a week prior to each event. Therefore, the *CN* was adjusted upward to reflect the reduced losses which occur under those conditions. After adjusting the *CN* to account for antecedent moisture conditions, the model produced hydrographs at the watershed outlet that matched the peak and general shape of the observed hydrographs for each event. Figure 7 shows the observed and computed hydrographs for the March - April 1993 event. The time to peak for the computed hydrograph did not exactly correspond to the time to peak for the observed hydrograph. One factor which may have contributed to the difference in timing is that the data on stream cross sections for this model were not very detailed. However, for the purpose of this study, the peak flow and volume of flow were the more important hydrograph characteristics, and those were recreated effectively by the model.

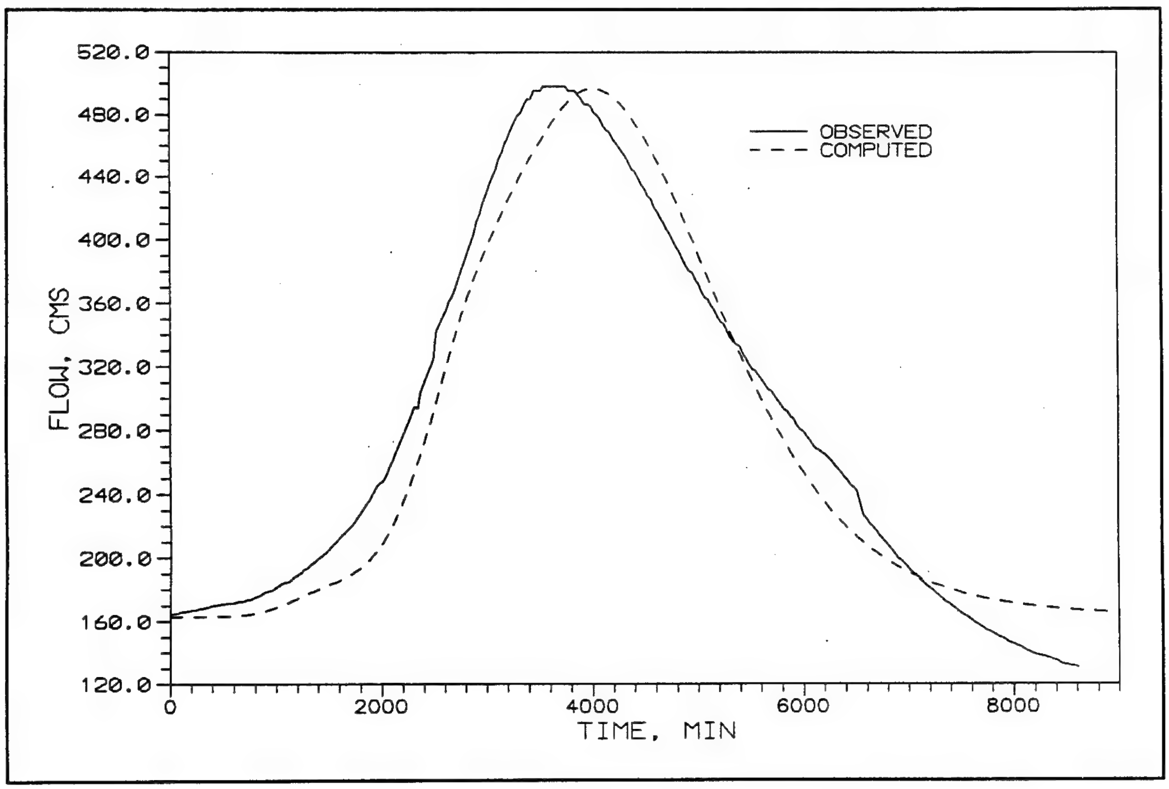

Figure 7. HEC-1 model verification, observed versus computed events

5 Watershed Evaluation

Proposed Alternatives

A series of alternatives to reduce peak flows was developed by the SAST. Using the verified model, the potential reduction in peak flow for each of the alternatives was evaluated for a series of design storms. The alternatives developed by SAST and how they were applied to the West Fork Cedar River watershed are detailed below.

Land conservation practices

This alternative involved the implementation of planned land conservation practices which are designed to reduce runoff and soil erosion. The United States Department of Agriculture, Soil Conservation Service in Des Moines, IA, provided data which included the reduction in *CN* as a result of these land conservation practices in each county in Iowa. Table 2 provides a breakdown of the counties that encompass the West Fork Cedar River watershed, the reduction in *CN* for land conservation practices in each county, and shows a weighted reduction in *CN* over the entire watershed for this alternative of 1.23.

Conservation Reserve Program (CRP)

This alternative involved the inclusion of highly erodible land in CRP, which results in that land being removed from cultivation and returned to permanent cover such as grasslands. The result is a reduction in the runoff from this land. As with the land conservation practices, the SCS provided data for each county in Iowa for CRP acreage, and the resultant estimated reduction in *CN*, as shown in Table 2, is 0.97.

Land conservation practices and CRP

This alternative was simply a combination of the previous two alternatives. Again, SCS data were provided for this alternative, with an estimated *CN* reduction of 2.20, as detailed in Table 2.

Table 2
West Fork Cedar River Watershed Curve Number Calculations

County	Approximate Area in Watershed (km^2)	Percent of Watershed Area	CN Reduction for Cons. Practices - County [1]	Weighted CN Reduction for Cons. Practices - Watershed	CN Reduction for CRP Acres - County [1]	Weighted CN Reduction for CRP Acres - Watershed	CN Reduction for Cons. and CRP - County [1]	Weighted CN Reduction for Cons. and CRP - Watershed
Black Hawk	13	0.6	0.80	0.0048	0.19	0.0011	0.99	0.0059
Butler	745	33.5	0.82	0.2747	1.38	0.4623	2.20	0.7370
Cerro Gordo	470	21.2	1.05	0.2226	0.97	0.2056	2.02	0.4282
Franklin	980	44.1	1.63	0.7188	0.68	0.2999	2.31	1.0187
Hancock	13	0.6	1.49	0.0089	0.63	0.0038	2.12	0.0127
Watershed Total	2221	100.0		1.23		0.97		2.20

[1] CN reduction data for each county provided by the USDA Soil Conservation Service, Des Moines, IA.

Wetland storage

This alternative involved inclusion of as much wetland storage as possible within the watershed. The intention of this alternative was that some runoff would be temporarily stored in wetland areas, thus attenuating the peak of a given flood event. An examination of the West Fork Cedar River watershed indicated that there are relatively few potential wetland sites. Creation of wetlands with enough storage potential to achieve a reduction in peak flows during flooding events would envelop a significant amount of cropland. Therefore, this alternative was not considered as a viable scenario for flood peak reduction on this watershed and was not modeled during this study.

Flood prevention structures

Small flood control structures which would control 35-50 percent of the drainage area were proposed in this alternative. As with wetland storage, the availability of sites for such structures in this watershed was very limited. There are very few, if any, sites that would be feasible for flood control since most of the valleys are wide with very low grades such that large areas of valuable cropland would be impacted (U.S. Department of Agriculture 1974). This alternative was not modeled during this study.

Design Storms

Four design storms were used to analyze the alternatives modeled during this study. Storms of 24-hr duration with return periods of 1, 5, 25, and 100 years were used, and the precipitation amounts for each of those storms were determined from the National Weather Service Technical Paper 40 (National Weather Service 1961). Data from Technical Paper 40 provide point estimates of precipitation for a given duration and return period. For modeling the West Fork Cedar River, those point estimates were extended to develop an average precipitation depth over the entire area of the watershed. In practice, a reduction factor is typically applied to the point precipitation amounts when applying the precipitation over a larger area. This reduction factor takes into account that the average precipitation over an area will generally be less than the point precipitation values taken from Technical Paper 40. Thus, the areal precipitation depths were determined by applying an areal reduction factor to the point precipitation values based upon the area of the watershed. Table 3 shows the point rainfall amounts for each of those storms as given in Technical Paper 40, with an areal adjustment for the 2,220-sq-km watershed (Chow, Maidment, and Mays 1988).

In addition to the total depth of precipitation for each storm, the temporal distribution of the rainfall was needed. There are a variety of methods available for developing time distributions for storms, and the method used in this

Table 3
West Fork Cedar River Watershed Rainfall Depth Calculations

Storm duration (hr)	24	24	24	24
Return period (yr)	100	25	5	1
Point rainfall depth (in.)[1]	6.36	5.12	3.82	2.53
Areal adjust. factor for 2,220 km^2	0.903	0.903	0.903	0.903
Adjusted depth (in.)[1]	5.74	4.62	3.45	2.28
Adjusted depth (mm)	145.9	117.4	87.6	58.0

[1] To convert inches to centimeters, multiply times a factor of 2.54.

study was developed by the Soil Conservation Service. The SCS developed synthetic storm hyetographs for use in the United States for storms 6 and 24 hr in duration. There are four different 24-hr-duration storm distributions, which are called Types I, IA, II, and III. Each storm distribution is applicable for a particular portion of the country. For the West Fork Cedar River, the SCS Type II distribution applies and was used for this project. Table 4 provides the cumulative storm hyetograph for the SCS Type II rainfall distribution (Chow, Maidment, and Mays 1988).

Table 4
SCS Type II 24-Hour Distribution

Hour	P_t / P_{24}
0.0	0.0
2.0	0.022
4.0	0.048
6.0	0.080
7.0	0.098
8.0	0.120
8.5	0.133
9.0	0.147
9.5	0.163
9.75	0.172
10.0	0.181
10.5	0.204
11.0	0.235
11.5	0.283
11.75	0.357
12.0	0.663
12.5	0.735
13.0	0.772
13.5	0.799
14.0	0.820
16.0	0.880
20.0	0.952
24.0	1.000

6 Results

The HEC-1 model was run for each of the alternatives described in the previous chapter using each of the four storms detailed in Table 3. For each alternative, the model was first run for a "base condition." That base condition reflected the existing conditions in the watershed with the acres currently in CRP removed from CRP such that the base condition would reflect a watershed with no CRP program in place. From that base condition, the *CN* was reduced by the amount reflected in Table 2 for each of the four design storms, i.e., the *CN* was reduced by 1.23, 0.97, and 2.20 for the land conservation practices, CRP, and combined alternatives, respectively. The peak flow resulting from each scenario was then compared to the peak flow obtained for the base condition before reducing the *CN*. Figures 8, 9, 10, and 11 provide hydrographs from the four design storms for the base condition and three alternatives. The peak flow for each hydrograph and comparisons of each alternative to the base condition are summarized in Table 5.

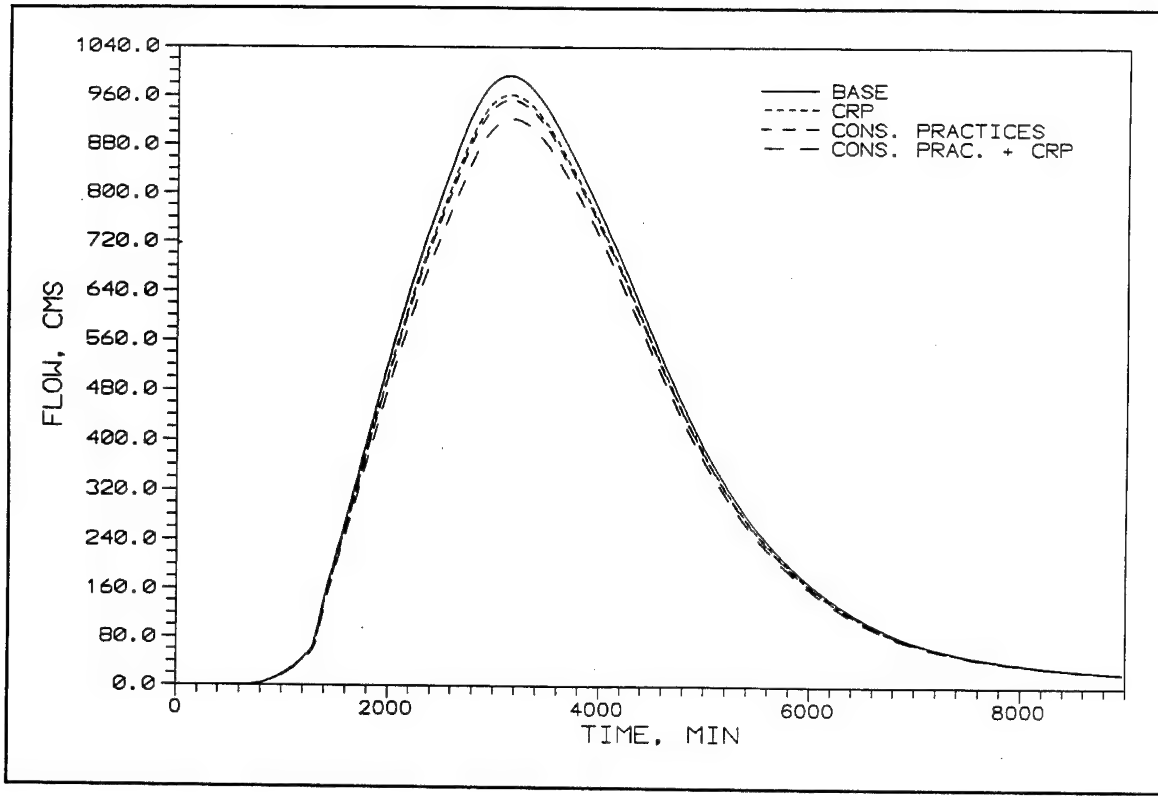

Figure 8. Computed hydrographs for 100-year return period storm

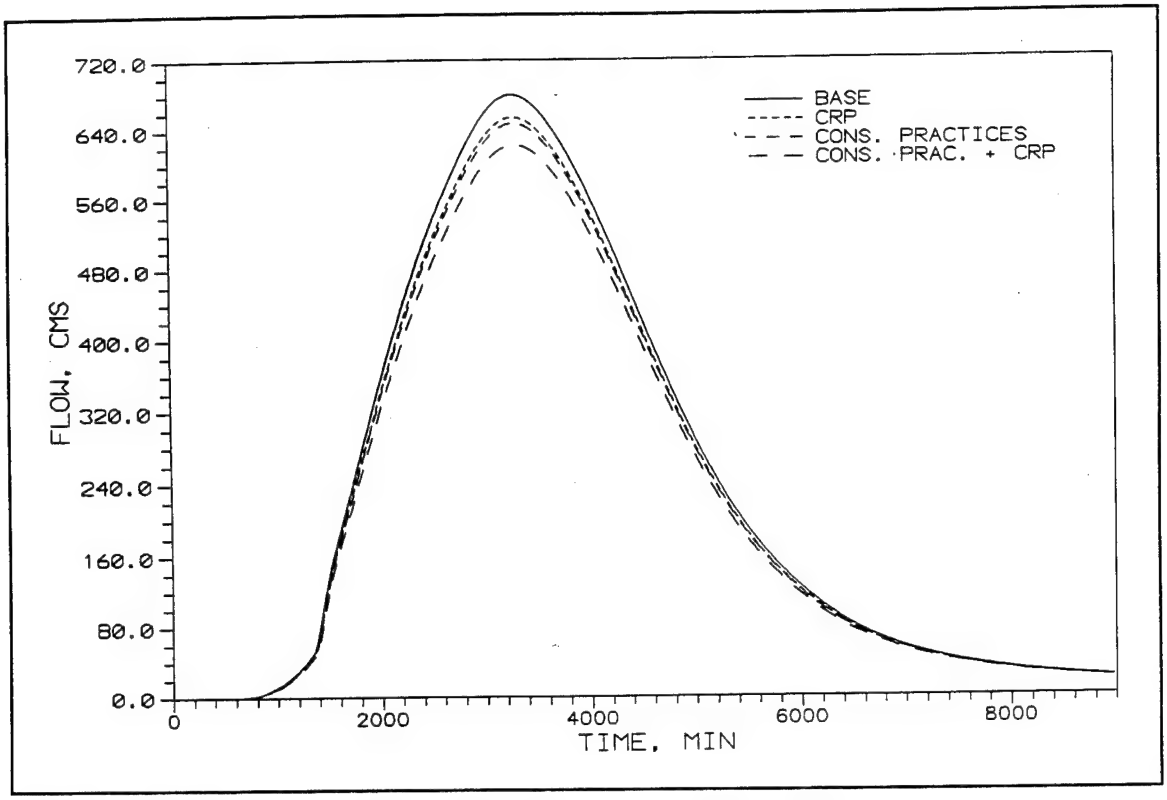

Figure 9. Computed hydrographs for 25-year return period storm

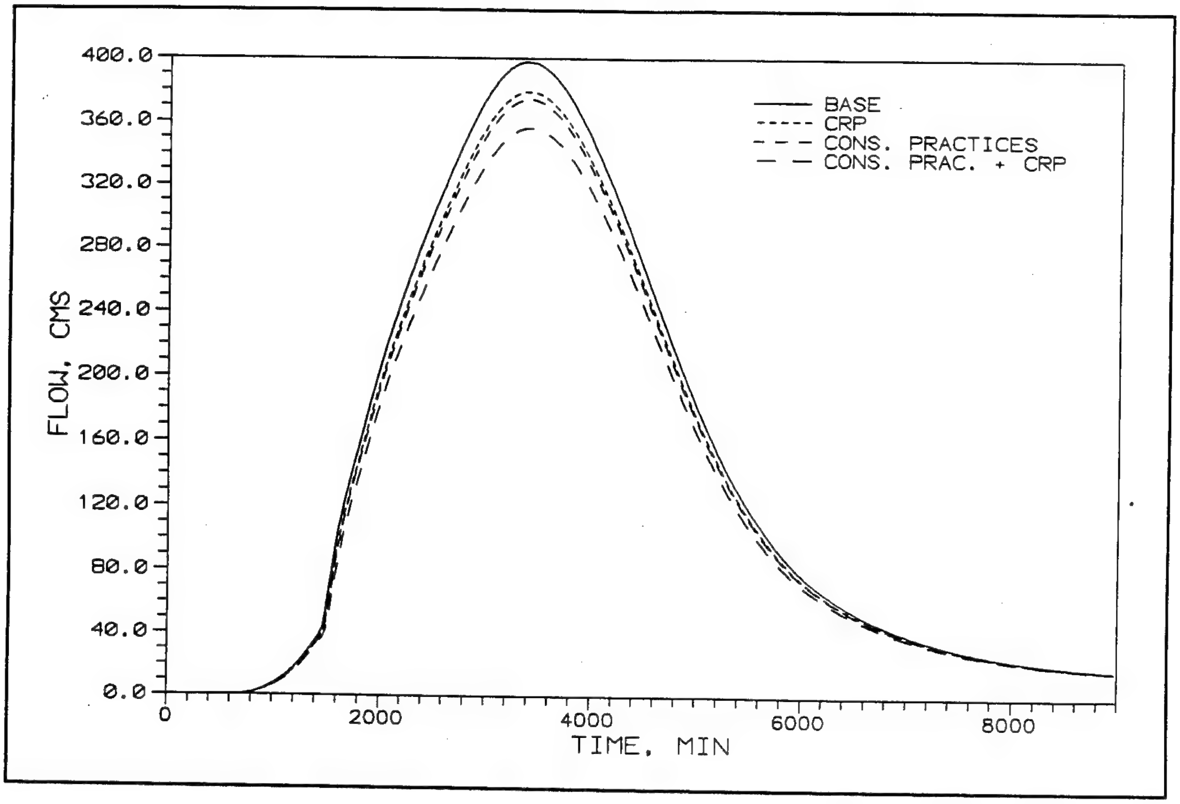

Figure 10. Computed hydrographs for 5-year return period storm

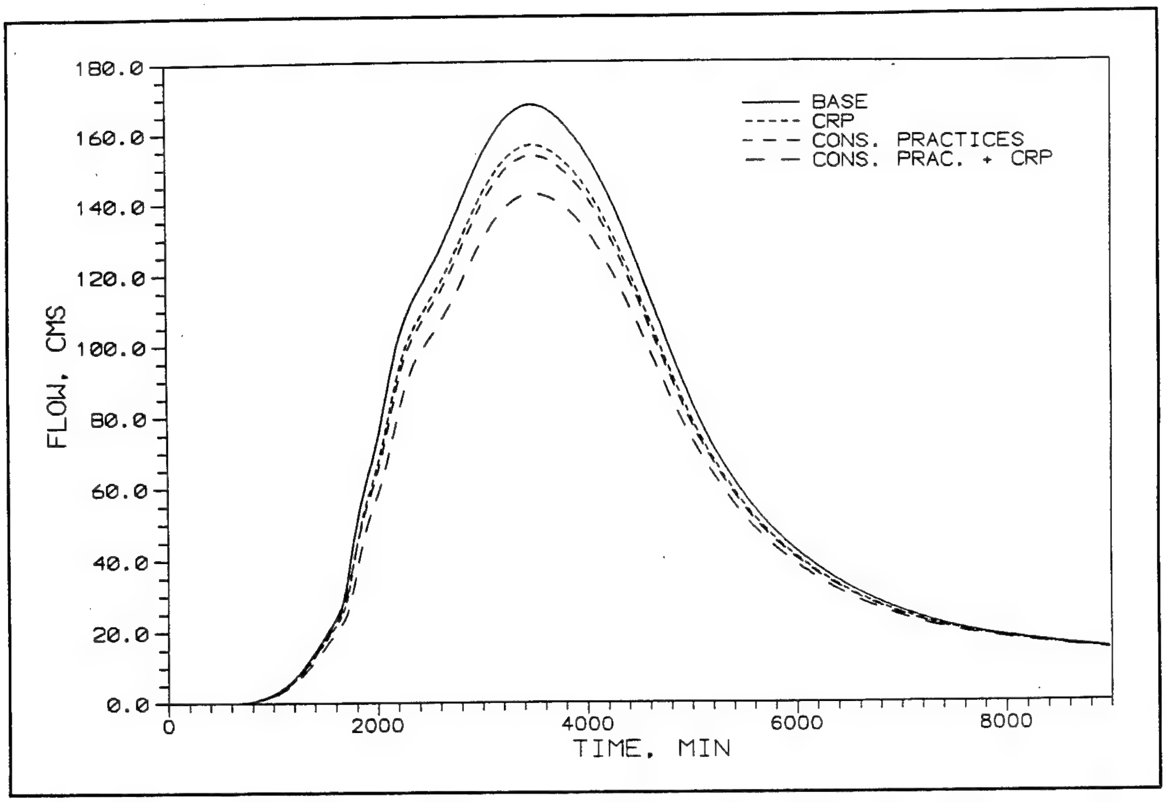

Figure 11. Computed hydrographs for 1-year return period storm

Table 5
West Fork Cedar River Watershed Peak Reduction Estimates for Alternatives

Storm Return Period	Alternative [1]	Curve Number Reduction	Q_{peak} (m^3/s)	Percent Reduc. in Q_{peak}
100 yr	Base	-	993	-
	Cons. Practices	1.23	953	4.0
	CRP	0.97	962	3.1
	Cons. Prac. + CRP	2.20	922	7.2
25 yr	Base	-	680	-
	Cons. Practices	1.23	648	4.7
	CRP	0.97	655	3.7
	Cons. Prac. + CRP	2.20	624	8.2
5 yr	Base	-	398	-
	Cons. Practices	1.23	374	6.0
	CRP	0.97	379	4.8
	Cons. Prac. + CRP	2.20	356	10.6
1 yr	Base	-	168	-
	Cons. Practices	1.23	154	8.3
	CRP	0.97	156	7.1
	Cons. Prac. + CRP	2.20	143	14.9

1 Definitions of Alternatives:
Base = Base condition (existing conditions with current CRP acres removed from CRP).
Cons. Practices = Base condition with curve number reduction due to planned land conservation practices.
CRP = Base condition with curve number reduction for CRP acres.
Cons. Prac. + CRP = Base condition with total curve number reduction due to planned land conservation practices and CRP acres.

7 Conclusions

Model Predictions

The model established for the West Fork Cedar River watershed during this study indicated that a reduction of the runoff *CN*, as estimated by SCS for the various alternatives, should result in a reduction of the peak flow from the watershed. These results are what would be expected, since a reduction in *CN* reflects an increase in the amount of losses and thus a reduced amount of excess precipitation available for runoff. The maximum estimated reductions in peak runoff were for alternatives which combined land conservation practices with CRP for the maximum potential reduction in *CN*, which was 2.20 for this watershed. The reductions in peak runoff for that *CN* reduction of 2.20 ranged from 7.2 percent for the 100-year return period storm to 14.9 percent for the 1-year return period storm. The other alternatives also showed estimates of reduced peak flow, but to a lesser degree as they involved a smaller reduction in *CN*.

Model Limitations

Although every effort was made to create a model of the West Fork Cedar River watershed which accurately reflects the conditions in the watershed, there are two limitations which must be noted. First, the model was created with marginal data for stream cross sections. Detailed cross-sectional data for the stream channels in the watershed would have provided the most accurate model, but time constraints for this study made the acquisition of such data impossible. Thus, general stream cross-section characteristics were used based upon a field reconnaissance trip to the site. Secondly, the entire modeling effort was completed during an 8-week period, which included the acquisition of all data, creation of the watershed model in GeoShed, generation of the HEC-1 model, comparison of the model to observed data, and running the model with the various alternatives. That general cross-section data and 8-week period were adequate for creating a model to show general trends and relative changes in peak flow for various conditions, but additional data and additional verification to observed events over a wider range of peak flows would be required to provide a model that would reliably predict specific flows

from the watershed. It must also be noted that this study includes only a discussion of the amount of flow from the watershed and does not address the stage or flooded area associated with those flows. A more detailed study involving hydraulic modeling of the stream and river system would be required before estimates of stage and the resulting flooded area could be considered.

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Appendix A Notation

AREA	Area of the watershed or subbasin over which the unit hydrograph is to be applied
CN	Curve number
F_a	Continuing abstractions
I_a	Initial abstractions
L	Maximum flow distance in the watershed (feet)
P	Depth of precipitation
P_e	Excess precipitation or runoff
q	Discharge at time t
q_p	Peak discharge
S	Potential maximum retention, (1,000/CN) - 10
t	Time
TLAG	Lag in hours between the center of mass of rainfall excess and the peak of the unit hydrograph
T_p	Time from beginning of rise to peak
x	Coordinate that represents easting of a data point
y	Coordinate that represents northing of a data point
Y	Average watershed slope (percent)
z	Coordinate that represents elevation of a data point

Δt HEC-1 computational time interval

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13.ABSTRACT ***(Maximum 200 words)***

The Scientific Assessment and Strategy Team (SAST) was formed by direction of the White House to provide technical guidance on recovery efforts and future floodplain management issues in the Upper Mississippi River Basin as a result of the unprecedented flooding that occurred during the spring and summer of 1993. In support of the SAST efforts, several watershed modeling studies were conducted to analyze the potential for reducing peak flow via several nonstructural watershed management approaches. This report summarizes the study that was conducted on the West Fork Cedar River Watershed in Iowa. The watershed was modeled using HEC-1, and the effects of various watershed management scenarios were tested with the model. Results which indicate the estimated potential reduction in peak flow due to those watershed management approaches are summarized.

14.SUBJECT TERMS

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